Reviews • KEYNOTE REVIEW

Teaser The reaction of the scientific community to COVID-19 is the most rapid outbreak response in recent history. Developing treatments for COVID-19 and preparing for future epidemics requires long-term investment in antiviral research.

Learning from history: do not flatten the curve of antiviral research!

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Here, we explore the dynamics of the response of the scientific community to several epidemics, including Coronavirus Disease 2019 (COVID-19), as assessed by the numbers of clinical trials, publications, and level of research funding over time. All six prior epidemics studied [bird flu, severe acute respiratory syndrome (SARS), swine flu, Middle East Respiratory Syndrome (MERS), Ebola, and Zika] were characterized by an initial spike of research response that flattened shortly thereafter. Unfortunately, no antiviral medications have been discovered to date as treatments for any of these diseases. By contrast, the HIV/AIDS pandemic has garnered consistent research investment since it began and resulted in drugs being developed within 7 years of its start date, with many more to follow. We argue that, to develop effective treatments for COVID-19 and be prepared for future epidemics, long-term, consistent investment in antiviral research is needed.

Introduction

From time immemorial, infectious diseases have ravaged mankind. Only 100 years ago, tuberculosis (TB) was still one of the top three leading causes of death in the USA [1]. Fortunately, science advanced dramatically during the 20th century, changing the ways in which our society treats infectious diseases. Current preventative vaccines and drugs are catered to treat long-lasting and/or chronic infections or infectious diseases that recur annually or on a regular basis, such as HIV,

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GLOSSARY

Antiretroviral therapy (ART) Treatment regimen for HIV-positive patients that involves the combination of multiple antiretroviral medications in order to suppress replication of HIV and halt progression to AIDS.

arXiv.org Online, open-source platform for the distribution of preprints that are moderated but not peer reviewed.

Betacoronavirus One of the four genera of coronaviruses; examples include SARS-CoV-1, SARS-CoV-2, and MERS-CoV.

High-throughput screening (HTS) Used in drug discovery efforts; automated method for rapid screening of large compound libraries for activity against a given target or another relevant metric.

Machine learning Subset of artificial intelligence and part of QSAR; computer algorithms which can adapt or 'learn' from experience rather than being explicitly programmed to perform certain functions.

Molecular docking A molecular modeling technique which is often used to determine the optimal structural configuration of a ligand in relation to a target protein.

Quantitative structure–activity relationship (QSAR) models In the context of drug design, statistical models that relate (predict) relevant characteristics such as the biological activity of compounds to (from) numerical representations of different aspects of molecular structure (descriptors).

TB, hepatitis C, influenza, and so on. However, the major viral disease outbreaks that have plagued society over the past two decades do not follow this pattern. In fact, they have shown that the scientific community is not adequately prepared to offer or rapidly develop effective treatments when an outbreak happens [2]. As a consequence, all countries have to adopt nontherapeutic measures to slow the progression of the epidemic and 'flatten the curve' to limit the burden of the disease on the healthcare system and allow better support to severely ill patients [3].

A recent study in the *New England Journal of Medicine* [4] estimated that the yearly cost of a pandemic could amount to ~US$60 billion dollars being spent worldwide on treatment, control, and prevention efforts. As seen in the current outbreak of the SARS Coronavirus 2 (SARS-CoV-2), this cost might be even higher because of restrictions on international trade and travel, closing of businesses, prohibition of large gatherings of people, and other social-distancing strategies [5]. Although these measures do help curb the spread of the disease, they have potentially devastating consequences: it was initially predicted that a large volume of cases over a short period of time would result in the USA having barely enough masks to last even 2 weeks into the pandemic [6]. There might also be other social and political ramifications: from a quick glance at the Google Trends data [7], one can see that, on Super Tuesday in the USA in 2020, the popularity of Google searches for 'coronavirus' was nearly three times that for 'Super Tuesday'. Also, because of prohibitions on gatherings of more than 25–50 people
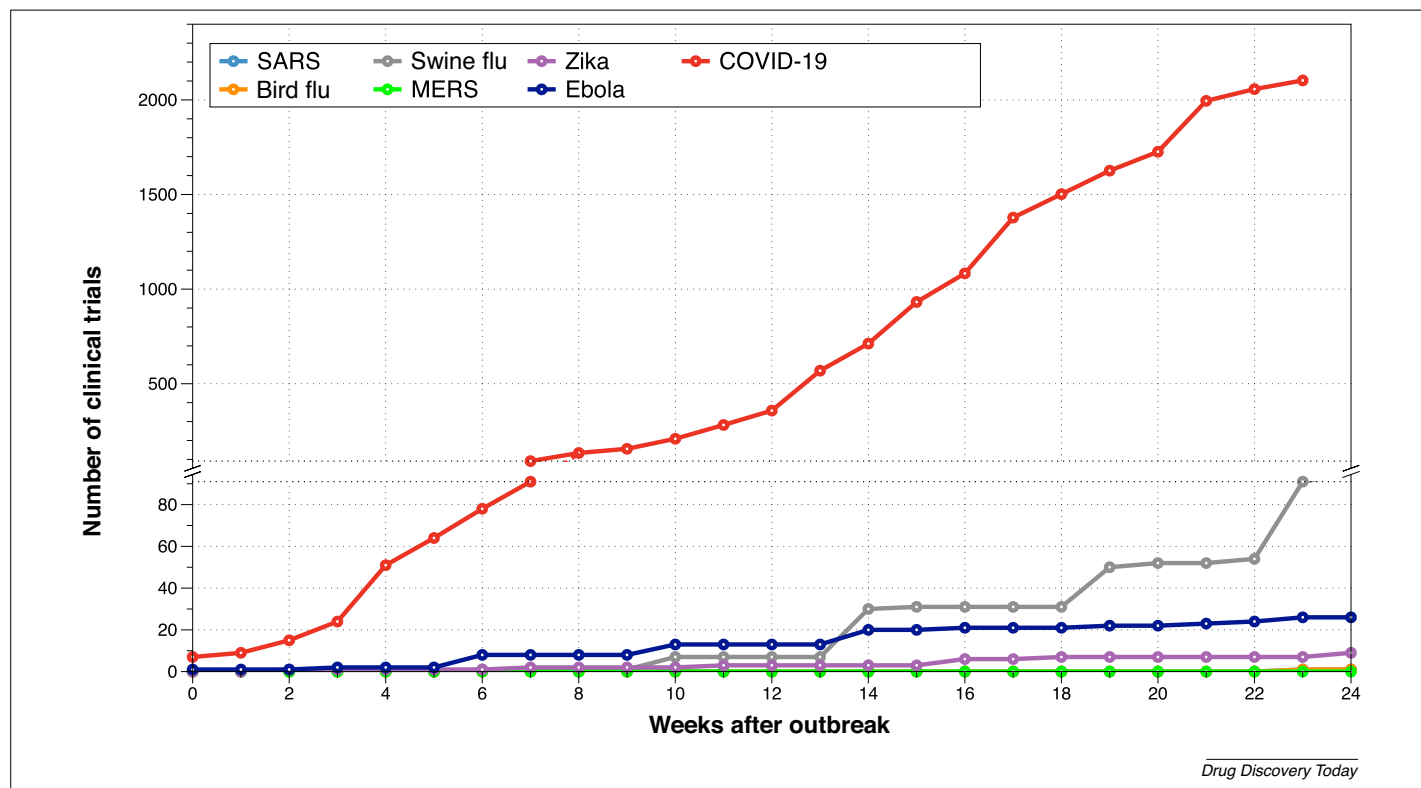

FIGURE 1

Total number of clinical trials launched per outbreak as the function of time during the first 24 weeks after the outbreak start date. The start date of each epidemic is defined as the date when authorities, such as the WHO, started listing data on the number of cases. Time is normalized for each outbreak according to this start date (week 0). We used the deposition dates and numbers of clinical trials as recorded in ClinicalTrials.gov. Abbreviations: COVID-19, coronavirus 2019; MERS, Middle East respiratory syndrome; SARS, severe acute respiratory syndrome.

in many cities and states, people might have stayed away from the polls out of fear of contracting the virus and might continue to do so in the future, possibly influencing the outcome of the 2020 US election [8,9].

The democratization of access to the internet has also facilitated the access of the general public to information through mediums such as major media outlets and even formal and informal data analytics [10,11]. For instance, Johns Hopkins University hosts a popular, regularly updated map of the reported cases of COVID-19 around the world [12] using data from the Chinese Centers for Disease Control and WHO situation reports. The new mantra, 'flatten the curve,' is also representative of the newfound exposure of the public to data science and analysis in response to the COVID-19 pandemic [13]. Likewise, the rapid growth of global communications systems has allowed media, government, and scientists alike to quickly access and share a large amount of data. This real-time sharing of information has been unprecedented. Although it permits governments to respond rapidly to epidemics through the dissemination of prevention and control methods, it can also facilitate public panic by stoking existing fears about an epidemic [14,15].

This rapid exchange of information applies to scientific data and publications as well: with increased access to the internet, the response of the scientific community has been enriched. We have observed an increasing number of articles being published for successive outbreaks in both peer-reviewed journals and various **ArXiv** (see Glossary) preprint servers over the past 20 years. Over the past

few months, both peer-reviewed journals [16,17] and ArXiv preprint [18,19] servers have been overpopulated with reports on known drugs or clinical candidates with possible anti-SARS-CoV-2 activity identified by computational approaches. However, despite many experimental and clinical studies, no effective drugs or treatments have emerged to treat the previous six epidemics of bird flu, SARS, swine flu, MERS, Ebola, and Zika as well as, thus far, COVID-19. This observation begs the question of whether the rapidity and bulk of immediate responses to epidemics are sufficient to enable the development of effective treatments.

In this study, we investigated historical data for seven major disease outbreaks of the past two decades: bird flu (H5N1), SARS, swine flu (H1N1), MERS, Ebola fever, Zika fever, and COVID-19. We assessed the response of the scientific community to these outbreaks over time, in addition to how effective that response was in producing vaccines and small-molecule antiviral drugs. To this end, we analyzed the number of publications, clinical trials, funding levels, and Google Trends data from the start of these epidemics until the present day. We observed that there has been little success in combatting outbreaks effectively while they were occurring, let alone after they have passed. By contrast, we also observed that these trends were different for HIV/AIDS, which has received continuous and uninterrupted attention from researchers around the world and for which multiple targeted therapies have indeed emerged. We expect this analysis to provide insights as to how to better mobilize both federal agencies and scientists to find treatments for COVID-19 as well as other future outbreaks.
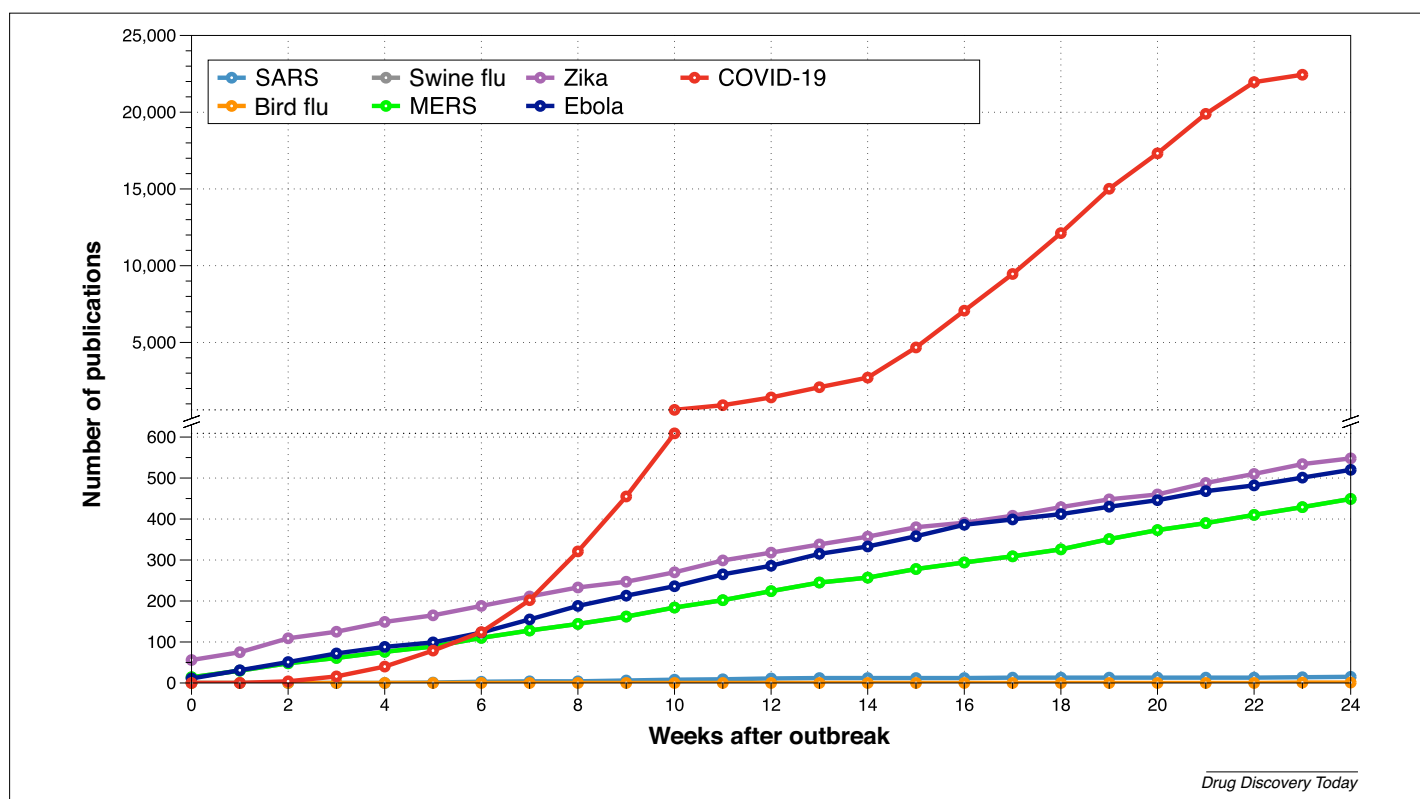
FIGURE 2

The evolution of the number of publications during the first 24 weeks after their respective outbreak start dates. The start date of epidemic is defined as the date when authorities, such as the WHO, started listing data on the number of cases. Time is normalized for each outbreak according to this start date (week 0). The data on publications include both peer-reviewed papers and preprints. The data were obtained from PubMed, BioRxiv, MedRxiv, ArXiv, and ChemRxiv. Abbreviations: COVID-19, coronavirus 2019; MERS, Middle East respiratory syndrome; SARS, severe acute respiratory syndrome.

Publications and clinical trials

We evaluated the number of publications (in both peer-reviewed journals and ArXiv preprint servers) and the number of clinical trials performed over the course of the epidemic to estimate the engagement and success of the scientific community in response to the seven major outbreaks of the past two decades: bird flu, SARS, swine flu, MERS, Ebola, Zika, and COVID-19. These metrics indicate the velocity with which the scientific community mobilizes to seek solutions to remedy an outbreak, as well as how this velocity correlates with other metrics, such as the number of confirmed cases and the number of people who have died from the disease. In addition, we evaluated the number of unique molecules and/or treatments being tested in clinical trials, because many were replicates of each other.

First, we looked at the response of the scientific community on weekly timescale (Figs 1 and 2). We examined the number of clinical trials (Fig. 1) and publications (Fig. 2) over the first 24 weeks of each outbreak, with week 0 corresponding to the time point when the federal authorities or the WHO first started reporting the data on the epidemic (for COVID-19, December 31, 2019 is considered the start date). On this standardized timescale, the number of clinical trials launched for COVID-19 greatly outnumbered that of any of the previous epidemics; the growth rate of publications on COVID-19 was also the highest. One can also see that, for more recent epidemics, such as Ebola and Zika, more clinical trials were launched during the first 24 weeks of the

epidemic than had been the case for previous epidemics, such as bird flu and MERS (Fig. 1). The only exception to this general observation was swine flu, which is an anomaly because H1N1 flu strains had been researched extensively before the start of the outbreak in 2009 as a result of the Spanish flu pandemic of 1918 and other past H1N1 epidemics [20,21]. This is in stark contrast to Ebola virus and Zika virus, which had caused smaller-scale outbreaks previously, yet had little to no information available on how to treat them [22,23].

Rate of response

Equally valuable is to compare the rate of response of the scientific community to the rate of epidemic growth. As a case study, we chose to compare data on SARS to that of SARS-CoV-2 (COVID-19). Interestingly, the number of total publications for SARS over time roughly followed the same trend as the number of cases, with an offset by a short time period of less than a month (Fig. 3). Likewise, rapid spikes in the number of cases correspond to slightly offset spikes in the number of publications on SARS by around the same period (16 days).

In comparison to SARS, COVID-19 does not show clear spikes in the number of publications or clinical trials corresponding to peaks and dips in the number of new cases or deaths (Fig. 4). Instead, the trends in the number of publications and clinical trials appear to follow the trends in the number of cases and/or deaths. Indeed, there is a correlation (R = 0.98) between the rate at which
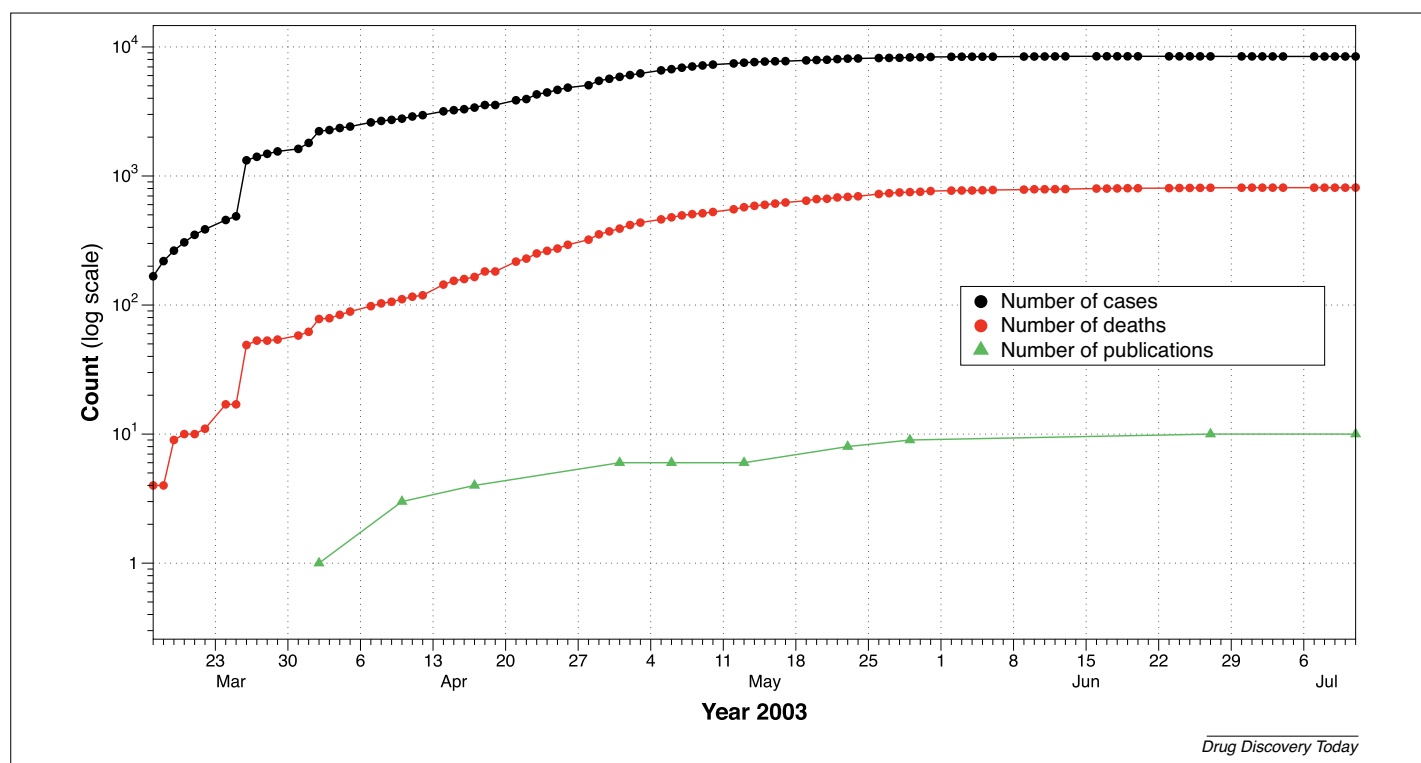
FIGURE 3

Cumulative number of publications and clinical trials over time for SARS in comparison with the global number of cases/deaths (log scale). Start date of epidemic is defined as the date when authorities such as the WHO started listing data on the number of cases. The data correspond to the first 3 months after severe acute respiratory syndrome (SARS) outbreak. The number of cases and deaths were obtained from the WHO and the number of publications from PubMed. In 2003, ArXiv was the only preprint server available and no preprints were published during the first 3 months of SARS epidemic. The search was based on the keywords 'SARS', 'Severe Acute Respiratory Syndrome', and 'SARS-CoV'. No clinical trials for SARS were deposited on ClinicalTrials.gov during the first 3 months after the outbreak.
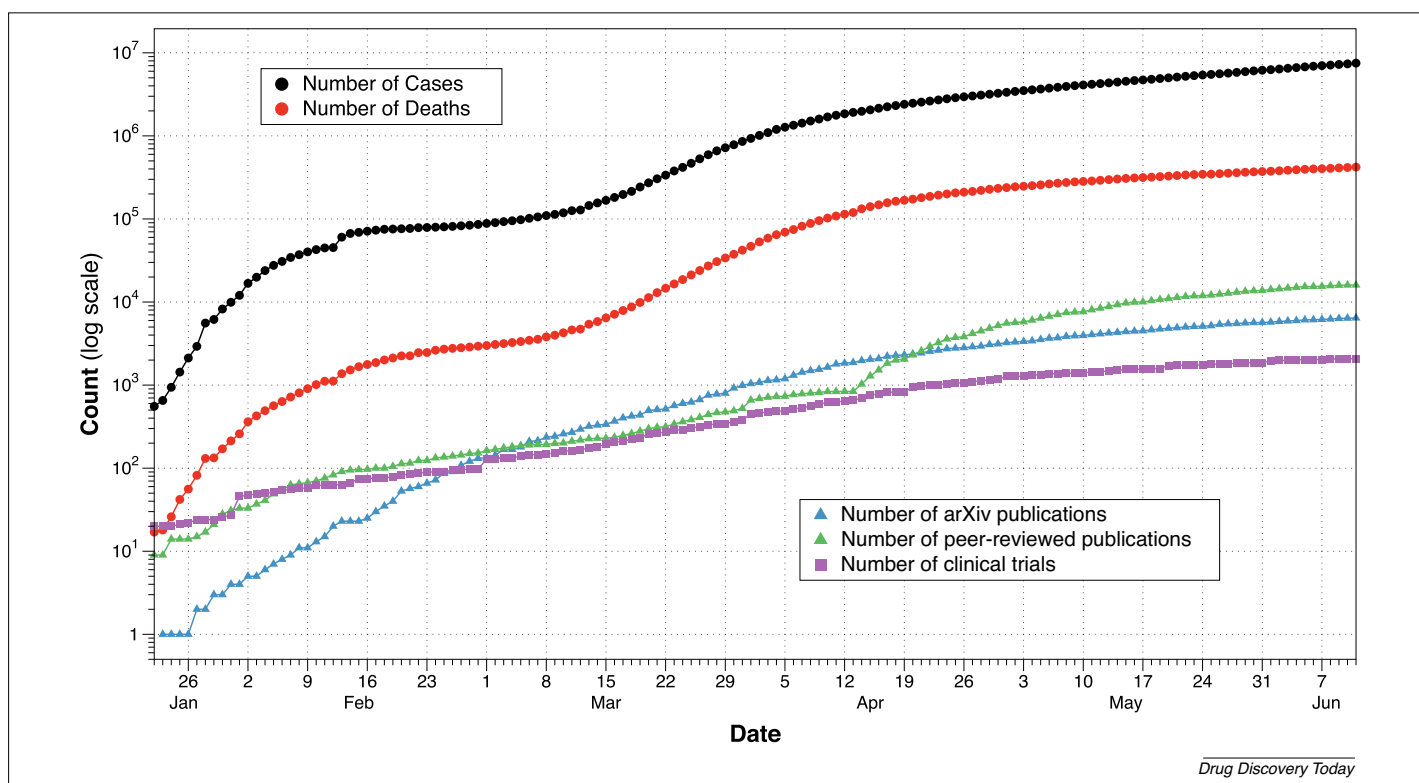
FIGURE 4

Cumulative number of publications and clinical trials over time for coronavirus 2019 (COVID-19) compared with the global number of cases/deaths (log scale). The start date of the epidemic is defined as the date when authorities, such as the WHO, started listing data on the number of cases. The data on cases and deaths were obtained from Johns Hopkins Coronavirus Resource Center website. Peer-reviewed publications were obtained via PubMed. Data on the number of preprints were obtained from BioRxiv, MedRxiv, ArXiv, and ChemRxiv. We used the deposition dates and numbers of clinical trials as recorded in ClinicalTrials.gov

the virus spreads throughout the population and intensity of research on COVID-19, as measured by the number of publications. Although looking for causality in these relationships is nonsensical, the number of new peer-reviewed publications appears to follow roughly the same logarithmic curve as the number of new cases recorded for COVID-19, whereas the rate of new publications in non peer-reviewed arXiv preprints appears to exceed even that of new COVID-19 cases (Fig. 4). The number of COVID-19 preprints in arXiv servers surpassed the number of COVID-19 papers in peer-reviewed journals in early March, highlighting the rise of online journals and preprint servers, as well as reflecting the shrinking period of time between the original observations and respective publications. This is also in direct contrast to SARS: more papers were published at a faster rate during this pandemic than in the SARS epidemic beginning in 2003. For example, eight peer-reviewed papers on COVID-19 had been published by the time there were 555 cases of the disease (January 22, 2020), whereas SARS only had one paper published by the time there were 1804 total cases (April 3, 2003). However, it is necessary to contextualize these observations in terms of the scientific output, not just by the rate of response. In this regard, we observed that the large number of studies conducted on SARS notwithstanding, no US Food and Drug Administration (FDA)-approved drug or vaccine to treat the disease has been developed in the 17-year period since the outbreak began (in 2003).

It is of particular interest to look at the evolution of both the number of publications and the amount of research funding from the beginning of each outbreak to-date (Fig. 5). This analysis shows, perhaps not unexpectedly, that, following the spike of the research interest in the initial phases of each epidemic, progressively fewer research papers were published for previous outbreaks after they ended. This trend probably reflects the lack of special funding for such research and, consequently, the lack of successful therapeutic development against the respective diseases. Indeed, fluctuations in research funding for each epidemic appear to follow the same spike-like trend as research publications (Fig. 5). This lack of research interest and/or funding outside of periods when these outbreaks are occurring is probably partially responsible for the current situation: no approved anticoronaviral medications exist and, as such, the world is frantically looking to repurpose existing drugs, such as chloroquine and hydroxychloroquine, which is premature and, according to at least some reports, could be potentially harmful to patients [24,25].

Public interest metrics

In addition to quantifying the response of the scientific community to these epidemics, we also collected Google Trends data on the principal search terms representing each of these diseases. Google Trends data do not represent the number of Google searches during a given time period but rather anonymized, aggregated, and normalized information about the relative proportion of searches on Google for a given search term, region, and time period [7]. This normalization protects against places with larger populations being weighted more heavily. A value of 100
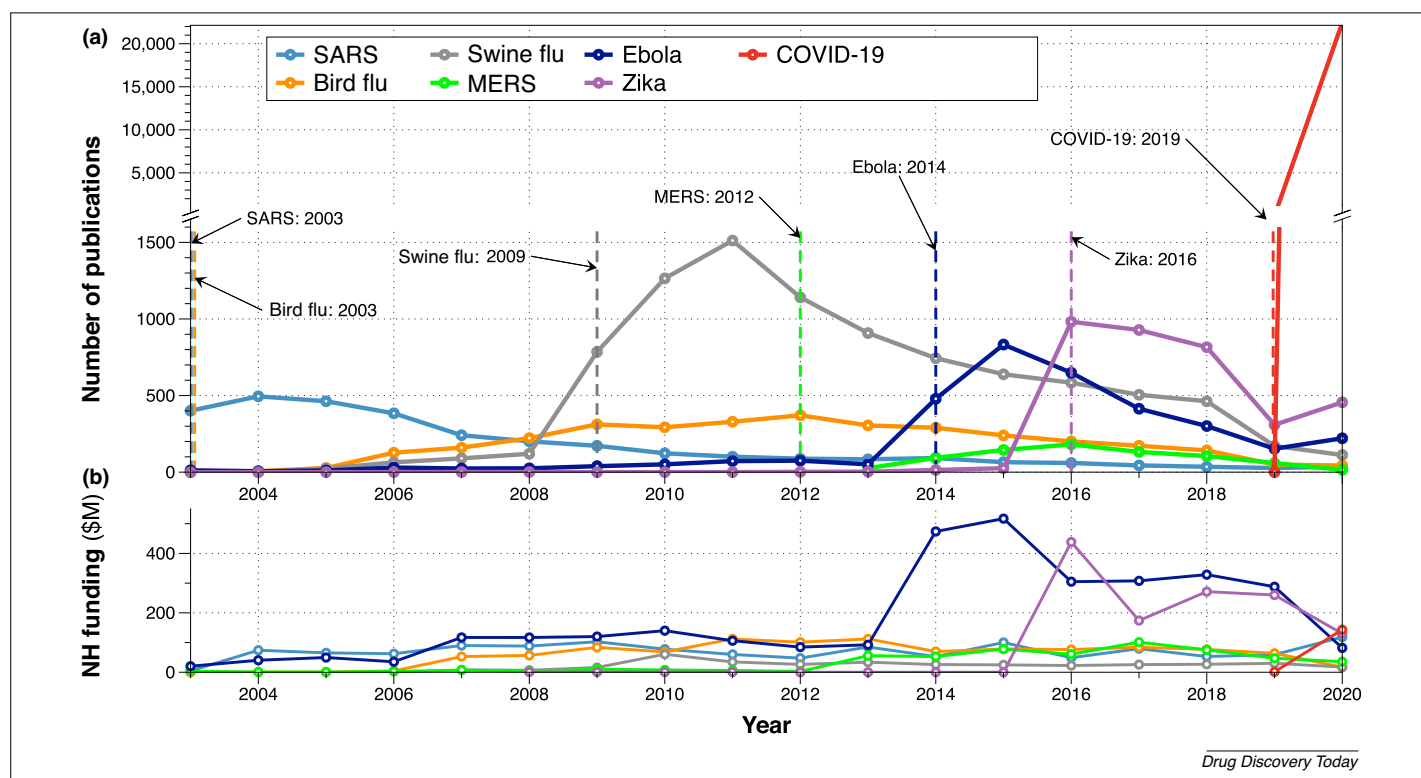
FIGURE 5

Number of publications **(a)** and funding **(b)** for antiviral research over time. Funding data were extracted from NIH RePORTER. The number of publications on antiviral drug research was obtained via PubMed. In both cases, the search was based on the co-occurrence of the keywords 'antiviral', 'drug', and 'research'. The start date of each epidemic is depicted as a vertical dashed line. Abbreviations: COVID-19, coronavirus 2019; MERS, Middle East respiratory syndrome; NIH, National Institutes of Health; SARS, severe acute respiratory syndrome.

corresponds to the maximum search interest in a topic for the given time and location, whereas a value of 50 corresponds to the search term being half as popular as it was at its peak. Google Trends, as a whole, serves as a fairly representative data source for the public perception of different news topics, indicating how interested people appear to be in a given topic over a specific period of time, with rapid peaks in search interest indicating a sudden increase in interest in a topic.

First, we gathered and standardized Google Trends data for each of the epidemics based on their start dates and relative time periods (no Google Trends data are available before January 2004; thus, some timepoints for bird flu and SARS were not available). When observing the first 30 months of the outbreaks, the response of the public to the epidemic appeared to peak during the first 8 months (Fig. 6). For diseases that had been previously studied, such as swine flu and Ebola hemorrhagic fever, there was already some search interest before the start date of the epidemic and, thus, the relative search interest in these diseases was higher during the earlier months of the epidemic. These outbreaks were shorter lived than some of the other diseases, such as MERS (infection continues today, although cases peaked in early 2014) [26], the relative search interest in which peaked an anomalous 20 months into the outbreak.

COVID-19 is interesting in that, although representing a novel virus, the number of relative searches peaked relatively close to those for all the previously studied illnesses (mentioned earlier)

and is following an increasing exponential trend (Fig. 6). The number of cases of COVID-19 worldwide is increasing in a nearly exponential fashion, with more people infected worldwide than in any of these previous epidemics besides H1N1 (swine flu). Additionally, for all diseases previously mentioned, their respective search interests peaked during the years when the epidemic was most severe (Fig. 6), so we should expect that the search interest for COVID-19 will steadily decrease when the pandemic begins to die down. However, as noted earlier, although we should expect such evolution of the general public interest, research into understanding this disease and developing powerful therapeutics should continue unabated.

Comparison to the HIV pandemic

Before the outbreak of SARS-CoV-2, previous studies had forecasted the re-emergence of a SARS-like **betacoronavirus** [27]. The potential for sustained transmission of SARS-CoV-2 or for the emergence of another novel betacoronavirus is alarming but has not been sufficient previously to garner any substantial drug discovery or vaccine efforts. These transmission dynamics and this potential for wide-scale, future pandemics makes COVID-19 distinct from the six previous epidemics examined earlier. Thus, the response to the HIV pandemic, which began in 1981, is also a worthwhile comparison to the current COVID-19 response.

The change in the number of cases, clinical trials, and publications for HIV is shown in Fig. 7, with marked time points delin-
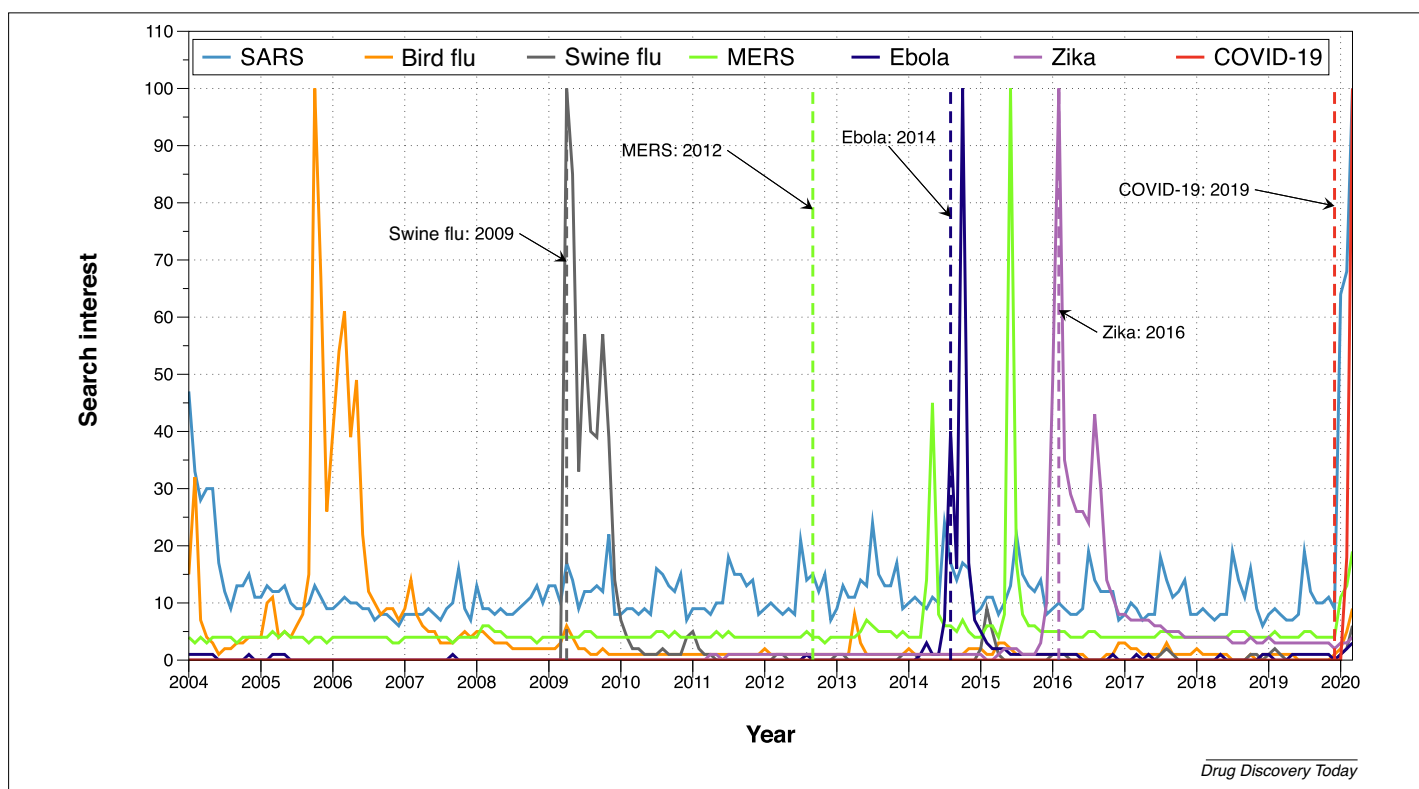
FIGURE 6

Relative search interest in diseases from January 2004 to the present day. Disease search terms are listed in the legend. Data were obtained from Google Trends (https://trends.google.com/trends/). The start date of each epidemic is depicted as a vertical dashed line. The search interest is normalized on a scale from 0 to 100. Abbreviations: COVID-19, coronavirus 2019; MERS, Middle East respiratory syndrome; SARS, severe acute respiratory syndrome.

eating when novel anti-HIV drugs were approved by the FDA. It is generally agreed that HIV can now be managed thanks to the powerful pharmacotherapies developed since the pandemic began during the early 1980s. This success is predicated on the significant and constant increase in federal funding for HIV over the course of the epidemic, rising from just a few hundred thousand dollars in financial year (FY) 1982 to more than US$34.8 billion in FY 2019 [28]. This support has allowed the research community to continue to study the disease, accounting for an average of >6000 papers published per year over the past 5 years, as annotated in PubMed.

Azidothymidine, better known as AZT, was the first drug approved in the USA to treat HIV and was tested in clinical trials and approved for use in patients in 1987, 6 years after the pandemic began [29]. AZT was originally synthesized for use as an anticancer agent [29] and was then repurposed against HIV. Given the toxicity of AZT and the rapid evolution of drug resistance [30], new compounds targeting various aspects of viral replication were eventually designed, encompassing different classes of antiretroviral drug, such as non-nucleoside/nucleotide reverse-transcriptase inhibitors, protease inhibitors, integrase inhibitors, and fusion inhibitors [30]. Currently, combinations of these different classes of antiretroviral drug are used in what is known as **antiretroviral therapy** (ART) to prevent the development of drug resistance. To date, 22 distinct medications and 22 combination therapies have been approved by the FDA, most during the early 2000s [30]. The first nonrepurposed drugs approved by the FDA

were lamivudine (a non-nucleoside reverse transcriptase inhibitor) and saquinavir (a protease inhibitor), both approved in 1995, nearly 15 years after the start of the pandemic [31]. Later during the pandemic, new drugs were developed in a streamlined process where lead compounds active against HIV *in vitro* were structurally modified to improve their efficacy and lower their cytotoxicity [32]. **High-throughput screening** (HTS) campaigns have also proven useful in identifying existing compounds with promise against HIV [33–35].

HIV serves as a prime example of how scientists in academia, government, and industry can combine efforts to combat a common threat. Even though it took 5 years to name the virus that caused the disease and 6 years to approve the first medication, cumulative scientific efforts ultimately paid off in the form of a diversity of treatment regimens available and a major improvement in life expectancy in most parts of the world [36]. Although SARS-CoV-2 might continue to circulate in humans for some time, it differs from HIV in that it has an airborne transmission route and a lower mutation rate because of polymerase proofreading abilities [27,37]. The latter is especially important to consider when developing therapies, vaccines, and antiviral medications. A lower mutation rate means that there is a higher probability of new treatments working for lengthier periods of time. It is also important to consider whether an infection is chronic or if recovered individuals can become sick again, examples being HIV and influenza, respectively. Epidemics last longer or can recur if the patho-
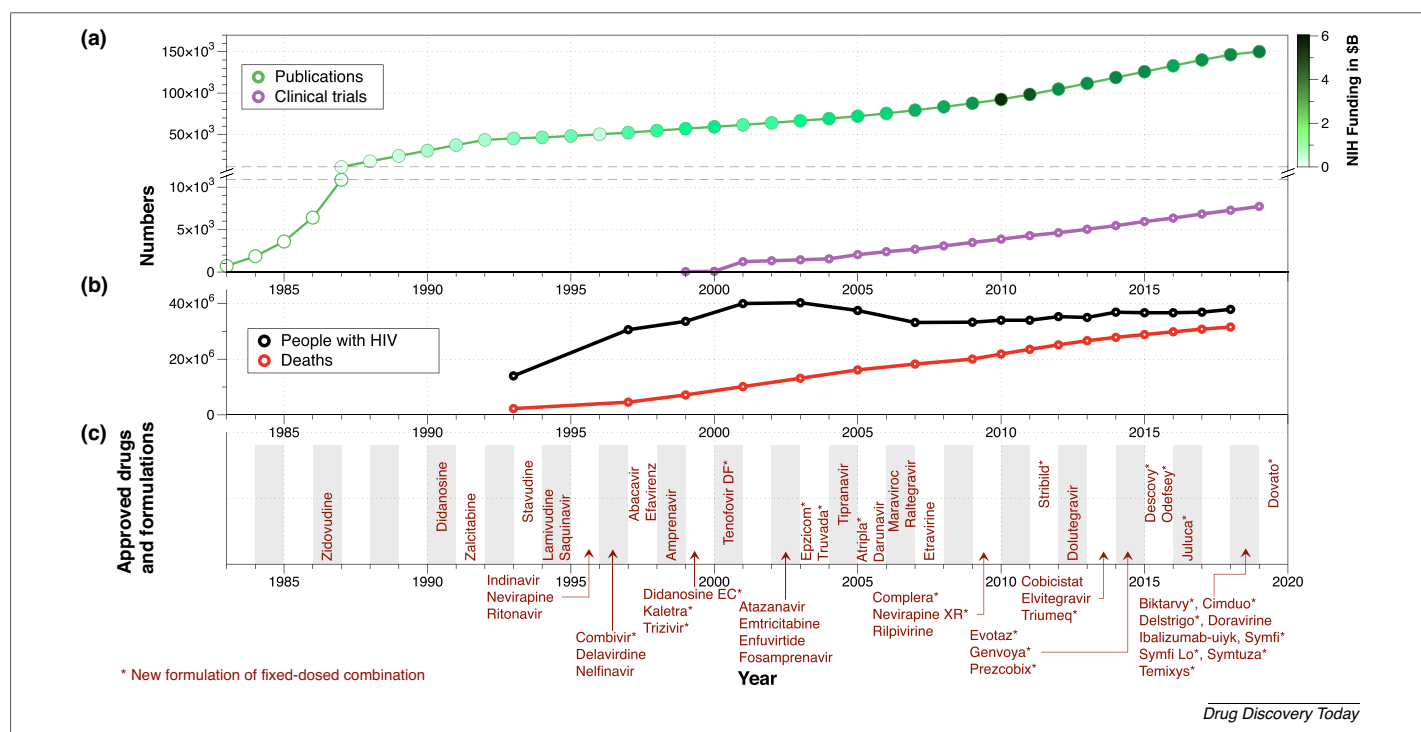
FIGURE 7

Cumulative number of publications and clinical trials **(a)** over the past decades for HIV compared with the global number of cases/deaths **(b)** as well as the approved drugs developed over this time period **(c)**. The count of clinical trials starts in 1999, whereas other metrics begin in 1993. The dates and numbers of clinical trials were obtained from ClinicalTrials.gov. The dates correspond to the time each trial was deposited to the server and do not reflect the actual study completion date (i.e., some studies might have been conducted before 1999). The numbers of people living with HIV and of deaths were obtained from WHO and UNAIDS annual reports. No reports were available before 1993. WHO and UNAIDS data for 2019 are not yet available. The timeline of appearance of US Food and Drug Administration (FDA)-approved anti-HIV treatments is highlighted. Abbreviations: COVID-19, coronavirus disease 2019; MERS, Middle East respiratory syndrome; NIH, National Institutes of Health; SARS, severe acute respiratory syndrome.

gen at hand meets these criteria, thus allowing more time for drug discovery to have a tangible output, such as ART for HIV and annual vaccines for influenza. Infection with SARS-CoV-2 is not known to be chronic and neither is it known definitively whether secondary infection can occur [38], but this or a similar virus is predicted to eventually re-emerge, meaning that drugs developed and tested now will be useful for future epidemics [23].

The sustained transmission of HIV within the human population, coupled with its extraordinary evolutionary rate, has provided a lasting incentive for pharmaceutical companies to continue identifying new antiviral medications to treat HIV [30]. Similarly, the expectation of another COVID-19 pandemic motivates rapid drug discovery efforts now for SARS-CoV-2. There are multiple efforts to identify existing drugs that could be repurposed to combat SARS-CoV-2 [39] (Box 1). Additionally, modern computational techniques, such as **quantitative structure–activity relationship** (QSAR) modeling, **molecular docking**, and **machine-learning** approaches are being used now in COVID-19 drug discovery efforts [17,40,41]. It should be expected that achieving success in developing COVID-19 therapies and preparing for future epidemics will require a substantial, lasting, and well-funded research effort. The sheer amount of resources at our disposal and the velocity of response of the scientific community so far, compared with the successful response to HIV, suggests that the development of drugs to treat COVID-19 in the coming years is attainable.

BOX 1

Key COVID-19 resources

Centers for Disease Control and Prevention (CDC) COVID-19 website (www.cdc.gov/coronavirus/2019-ncov/index.html)
COVID-19 SARS-CoV-2 preprints from medRxiv and bioRxiv (https://connect.biorxiv.org/relate/content/181)
COVID-KOP, Biomedical knowledge base integrated with CORD-19 literature collection (https://covidkop.renci.org/)
National Institutes of Health Coronavirus (COVID-19) website (www.nih.gov/health-information/coronavirus)
US National Library of Medicine ClinicalTrial.gov COVID-19 website (https://clinicaltrials.gov/ct2/results?cond=COVID-19)
US National Library of Medicine LitCovid curated literature hub for tracking up-to-date scientific information about the 2019 novel Coronavirus (www.ncbi.nlm.nih.gov/research/coronavirus/)
WHO COVID-19 website (www.who.int/health-topics/coronavirus#tab=tab_1)
WHO International Clinical Trials Registry Platform (ICTRP) (www.who.int/ictrp/en/)

Concluding remarks

In recent years, there has been a noticeable uptick in the response of the scientific community to outbreaks. We have observed that the Ebola (2014–2016) and Zika (2015–2016) outbreaks had more publications and clinical trials performed in a shorter time period than for previous outbreaks (Figs 1 and 2). However, the response of the scientific community to the COVID-19 outbreak represents

the most rapid response yet, with an unprecedented number of clinical trials and publications both in peer-reviewed journals and preprint servers. However, clinical and research efforts in response to past epidemics have failed to yield therapies during or after epidemic period; traditionally, it has taken years for effective drugs and vaccines to be developed and approved, much past the point at which they could be clinically useful and/or could be tested in clinical trials.

The speed of the response of the scientific community to major outbreaks has increased over the past two decades matching the increasing accessibility of information via the internet, but the outcome of this response has not changed. Despite the presence of various intergovernmental agencies, such as the WHO and the United Nations, individual nations have traditionally responded to large-scale epidemics in a disjointed fashion, and they desperately lack a pre-established, adequate, continuous, and centralized effort even within their own countries, let alone, internationally [23,42]. In the USA in particular, initial measures to predict or surveil disease outbreaks have been alarmingly either defunded or downsized over this same period in which the output of publications and clinical trials has increased [43,44]. As seen in the data presented in this study, the viruses that had already been studied before their respective epidemics garnered more publications and clinical trials in a shorter period of time than those that were understudied previously. Zika virus and Ebola virus had both been discovered long before they caused significant morbidity and mortality around the world; yet, they were not studied extensively, and thus, the correlated response of the scientific community was inefficient [23]. Had the scientific community had a consistent stream of funding to conduct research on coronaviruses that have hit humankind twice before the current pandemic, there might have been the prospect of pharmacotherapy on the near horizon [23].

When preparing for possible future epidemics, it is better to be safe than sorry; for example, the US Government has a stockpile of tecovirimat, a drug used to treat smallpox, in the event of an act of bioterrorism [45]. This drug was developed solely to prevent a future outbreak; smallpox was eradicated decades ago through global vaccination efforts. Similar prescient efforts are underway to prevent the next pandemic, such as the Rapidly Emerging Antiviral Drug Discovery Initiative (READDI). This initiative is aiming to create and stockpile a novel broad-spectrum antiviral drug in preparation for the next pandemic [46]. The history of HIV and AIDS shows clearly that steady interest and robust investment in the study of the disease have yielded the desired fruits. Although the speed of response to COVID-19 by both the research community and the public is unprecedented, the world needs to pay more attention to infectious diseases before they have the opportunity to cause lasting economic, social, and physical damage to people around the globe [47].

We hope that the data and their analyses presented in this article will stimulate both the funding agencies (governmental, private, etc.) and the scientific community to maintain their interest in searching for an efficient treatment for COVID-19, given the comparison with previous, large-scale epidemics. Given the unprecedented increase in clinical trials and publications, the growing public interest in the disease, and the looming threat of a future outbreak, it is unlikely that these trends will die down in the coming months and years. Vaccine development for COVID-19 is occurring at an unprecedented pace: on average, vaccine development takes 10 years, but there is a hope to have a vaccine available for emergency use by early 2021 [48]. However, global research efforts need to become more focused if we are to combat this pandemic effectively.

We believe that the ongoing research and clinical trials should be a product of international and intergovernmental collaboration driven by knowledge discovery and artificial intelligence approaches as applied to data from both past and present epidemics. Finally, substantial funding on the part of federal and state agencies, along with private foundations, is necessary to support massive research efforts to find a cure or a vaccine more quickly than in the past, and to stay prepared for future outbreaks of viral diseases. It is not enough to say that there are more resources available at our disposal now than ever; it is a matter of using these resources effectively. The historical response to HIV sets a precedent for success in the fight against emerging infectious diseases. We shall use this historical precedent and past failings as a guide for the current battle against COVID-19 and all future battles against other, imminent outbreaks.

Acknowledgments

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